ACCELERATED BIODEGRADATION OF CRUDE OIL ON ARCTIC SHORELINES

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INTRODUCTION

In the Arctic, large-scale cleanup operations following an oil spill, are required to protect the environment and minimize the ecological consequences of the oil spill.

The Arctic may generally be characterised as a remote and ecologically vulnerable area. The combined effects of remoteness and vulnerability indicate that mechanical cleaning-up of oil on arctic shorelines is neither possible nor desirable.

If the oil cannot be removed, then it has to be rendered less noxious in situ. A characteristic feature of stranded oil is, however, the decrease in total rate of decomposition compared to that of an offshore situation. Once the oil is stranded, it is no longer subjected to any mechanical energy input such as waves and currents, and soon the rate of decomposition declines. The total rate of decomposition of oil on the backshore is, therefore, of considerable interest. Of equal interest are any possible ways by which this rate of decomposition may be accelerated.

In this paper, data related to the effects of crude oil on the detrital foodchain are presented. The effects of adding a fertilizer to the oil slick, to optimize the chemical environment for microbial growth, are also shown.

METHODS

A beach located at Gluudneset near Ny Ålesund, Svalbard (79°N) was selected as a test site. This beach is a typical low energy environment. The salt-marsh vegetation is dominated by Carex ursina. A more detailed botanical description is given by Brattbakk et al. (1977).

In the supralittoral zone, test sites of 10 m^2 each were selected, and 10 L/m^2 of unweathered Forcados crude were added. The experiment included three test sites; an "oil alone" test site, an "oil and fertilizer" test site and a control test site. The fertilizer

applied consisted of 12.6% N, 5.6% P, 15.6% K, 1.2% Mg, 8% S and 0.02% B. At the "oil and fertilizer" test site 0.1 kg/m^2 of fertilizer was added. The experiment was initiated in the summer of 1976. The fertilizer experiment started in the spring of 1978, and the total experiment was monitored until the summer of 1979.

Decompositional processes of the oil have been measured by gas chromatography. Details concerning the method employed are found in Brattbakk et al. (1977).

Total soil in vitro respiration studies were performed using an infrared gas analyser in a static analytic procedure (Brattbakk et al. 1977). Invertebrates were extracted from soil cores according to A. MacFadyen (1962). Data for estimated heterotrophic activity per year are based on an assumed mean active period of 100 days.

Total heterotrophic fungi was estimated according to the Most Probable Number (MPN) technique (Brock, 1974) on Potato Dextrose agar (Difco).

RESULTS AND DISCUSSION

Total Rate of Heterotrophic Activity

Heterotrophic soil respiration may be used as a measurement of total heterotrophic activity. Soil respiration does, however, also include root respiration and the respiration of the rotting processes of all kinds of soil organic matter. The respiration of soil animals is also included. There is, therefore, no existing direct link between soil respiration and the rate of decomposition of oil in the soil. Indications as to the effects of microbiology on the oil slick can be obtained, however, by comparing the heterotrophic respiration of a control site with the heterotrophic respiration of the oiled test site.

The rate of heterotrophic respiration is primarily controlled by temperature. The effects of temperature and the amount of root respiration are shown in Table 1. The initial soil respiration at the oil site is lower than the respiration at the control site. These results are contradictory to the results obtained by Linkins et al. (1978) and Campbell et al. 1972). Some inhibition before an increase in soil heterotrophic activity, however, can be measured and has been reported (Sparrow et al., 1978).

Other trends in rates of soil respiration of the test sites are shown in Table 2. Here, it can be seen that the respiration rate at the "oil alone" test site did not increase during the years following the oiling. The rate of soil respiration showed a small but significant (at 10% significance level), decrease in respiration. The adding of fertilizer

TABLE 1 THE EFFECTS OF TEMPERATURE AND ROOT RESPIRATION ON TOTAL SOIL HETEROTROPHIC ACTIVITY IN THE CONTROL AND THE OILED TEST SITE. Data given in mg $CO_2/m^2/h$.

	CONTROL SITE		OIL ALONE SITE	
°C	Total Soil Heterotrophic Respiration	Root Respiration	Total Soil Heterotrophic Respiration	Root Respiration
0	-	-	35.6 ± 2.6	-
5	93.3 ± 19.4	29.5 ± 8.4	61.2 ± 16.7	18.5 ± 0.4
15	161.0 ± 7.9		143.4 ± 15.8	-

TABLE 2 RATES OF HETEROTROPHIC SOIL RESPIRATION IN THE DIFFERENT TEST SITES. Data in mg $CO_2/m^2/h$ at +5°C

Year	Control	Oil Alone	Oil and Fertilizer
1976	93.3 ± 19.4	61.2 ± 16.7	-
1977	-	62.5 ± 2	-
1978	-	54.0 ± 1	151.0 ± 2
1979	-	54.0 ± 1	100 ± 11

did, however, increase the rate significantly, (see Table 2). The effect was less typical the year thereafter, 1979. This shows that when an ordinary commercial agricultural fertilizer is applied, subsequent addition of fertilizer is necessary to keep the microbial activity at a high level.

The cumulative carbon loss from the "oil alone" and the "oil and fertilizer" test sites are shown in Figure 1. It can be seen that the addition of fertilizer had a marked effect on carbon release from the oil slick.

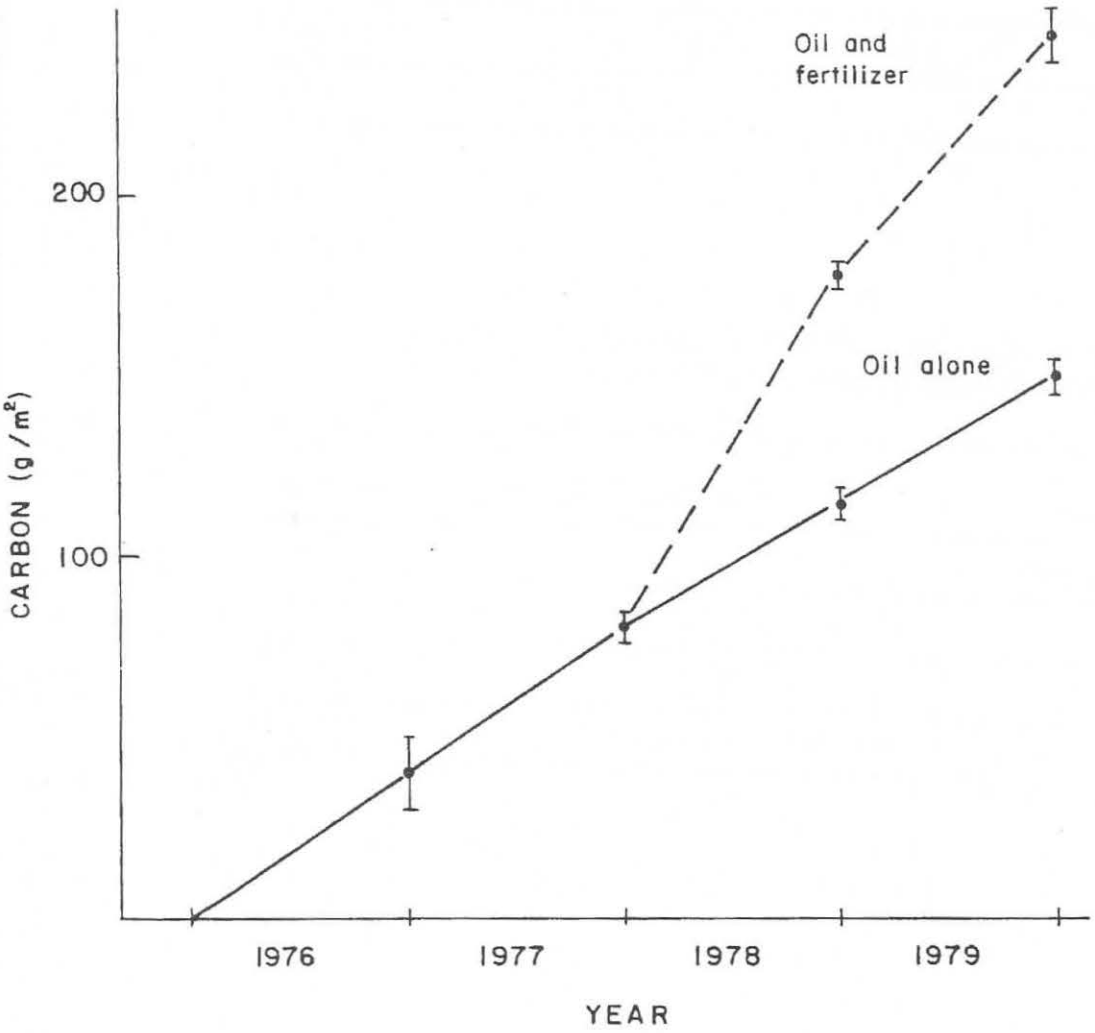

FIGURE 1 CUMULATIVE RELEASE OF CARBON FROM THE OIL ALONE AND OIL + FERTILIZER TEST SITE. Data given in carbon g/m^2/year ± SE.

The Detrital Food Chain

It might be of some interest to take a closer look at the biology behind this observed rate of heterotrophic activity. The detrital food chain in this habitat is dominated by fungal grazers, the Collembola. These invertebrates are the primary link between the rotting organic material of arctic shores and the insect feeding arctic shore birds. On the other hand, these invertebrates, when feeding on the microflora, especially the fungi growing on the oil, probably speed up the decomposition through stimulated fungal growth and increase aeration of the substrate. These effects have been demonstrated for other rotting organic materials (Withkamp and Asmus, 1975); (Maclean, 1974). It might be anticipated that these effects may be even more important to the decomposition of a substance with an extremely unfavourable C/N ratio, and which probably cannot decompose anaerobically.

The effects on shoreline invertebrates might also be seen in relation to the possibility of invertebrate "grazing" on stranded oil, and by this means contributing to the shoreline cleanup (George, 1961); (Holme, 1967); (Spooner, 1967) and (Smith, 1968).

The effects on the Collembola fauna of the test site are shown in Figure 2. Here it can be seen that fresh oil is a total catastrophe for this component of the shoreline biota. It must be stressed that as the total abundance of Collembola at the site was about 160,000 specimens per m^2 on the 14th of July 1976 (see Figure 2), the Collembola density declined to beyond 1000 specimens per m^2 as an immediate consequence of adding the oil to the soil.

The rate of recolonization of the oiled test field was also recorded, and shown in Table 3. Although the plot size was extremely small, and recolonization from the surroundings should be possible; this process has only taken place to a very limited extent. In Table 3, the recolonization of the different Collembola species is demonstrated. It must be stressed, however, that only a few specimens were recorded for each species, and consequently this recolonization is, from a quantitative point of view, of no importance. The further development in the Collembola community of the oiled and an unoiled test site was followed by one sample each year in 1978 and 1979. These tests show that the recolonization was still hampered in 1979. The population level within the oiled test field is still estimated to be less than 1000 specimens per m^2. If these results are compared to normal Collembola abundance, it can be stated that the fauna of the oiled field are, from a quantitative point of view, still negligible after four years.

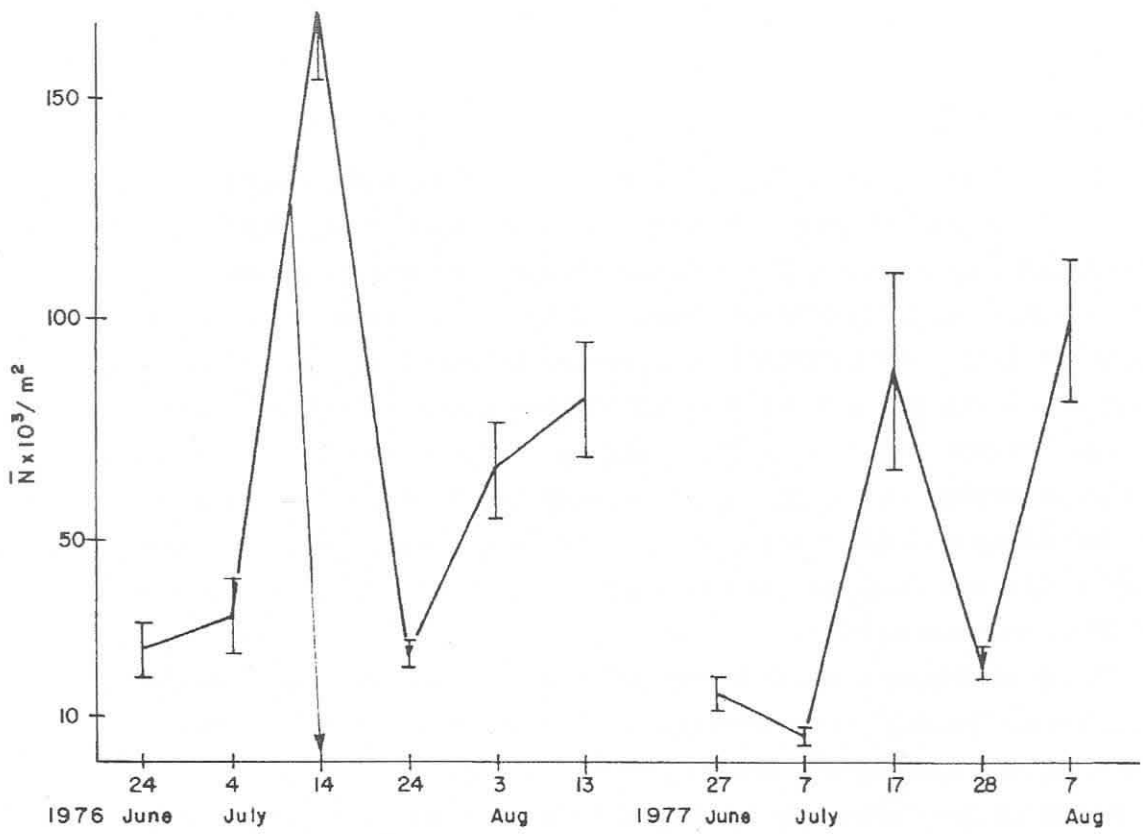

FIGURE 2 Natural development of abundance in the Collembola community. The arrow demonstrates the effect of the oil spill. Data ± Standard Error.

There may be many causes for these results. The oil may have made the soil anoxic, or the oil may still be toxic to invertebrates. Another possibility is, however, that a change has taken place within the fungivores' food chain. It may be that the Collembola could not find enough or suitable food in the oil slick. It may be that the fungal hyphae growing on oil with an unfavourable C/N ratio are either so nutrient poor that the Collembola cannot be sustained on this nutrition, or the amount of fungal hyphae is so small that fungivores cannot sustain life in this environment. Among other reasons, the "oil and fertilizer" test site was established in the summer season of 1978 in order to test this hypothesis. The results so far must be regarded as preliminary, but while in the "oil alone" test site the total Collembola population was only about 2% of the normal density according to the control site, the fertilized oil slick had increased its Collembola density to about 42% of normal density. Hence, this may be an indication that a more favourable C/N ratio in the oil slick promotes the rate of recolonization of fungivores and detritus feeding invertebrates.

TABLE 3 RELATIVE ABUNDANCE OF THE DIFFERENT SPECIES IN THE COLLEMBOLA COMMUNITY AT THE Carex ursina ZONE, AND RECOLONIZATION (+) AFTER THE OIL SPILL.

	Natural Relative	1976					1977			
	Abundance	14/7	24/7	3/8	13/8	27/6	7/7	17/7	28/7	7/8
Folsomia quadrioculata	46.0		+	+	+	+	+	+	+	+
Xenylla humicola	0.3			+	+					
Hypogastrura viatica	45.0				+			+	+	+
Onychiurus groenlandicus	4.8				+			+		
Hypogastrura hirsuta	2.7									
Sminthurides malmgreni	0.5									
Tetracanthella arctica	0.1									
Hypogastrura tullbergi	0.1									
Friesea nauroisi	0.1									
Onychiurus arcticus	< 0.1									
Folsomia bisetosa	< 0.1									
Isotoma anglicana	< 0.1									
Sminthurinus sp.	< 0.1									

These investigations on the effects of an oil spill on the detrital food chain were also followed up by an estimate of the most probable number of fungal propagules. The results are shown in Table 4. From Table 4 it can be seen that the same effects of fertilization are demonstrated on the fungal community as seen in the Collembola community. These results indicate that the biological decomposition of a shoreline oil spill is the result of the total activity of a heterotrophic food chain. An increased understanding of the ecological interaction within heterotrophic food chains may consequently turn out to be important in the understanding of total decompositional processes. At the present "state-of-the-art", the heterotrophic activity as a part of total decompositional processes in nature must, however, be studied as a "black box" phenomenon.

Total Decomposition

Following these biological characteristics of oil slick decomposition, the total rates of oil decomposition were also studied. The initial rates of evaporation from different oil film thicknesses are shown in Figures 3 - 5. In Table 5, the relative content of the different fractions of the oil present are shown. It is shown here that the rate of evaporation decreases with rising oil film thicknesses. After 6 days 48% of the 1 mm oil

TABLE 4 MPN COUNTS OF FUNGI IN THE DIFFERENT TEST SITES

	Control	Oil Alone	Oil and Fertilizer
MPN 10^4 + SE/g of dry soil 1979	13.5 ± 3.5	7.8 ± 1.1	20.0 ± 5.1

TABLE 5 RELATIVE CONTENT OF THE DIFFERENT FRACTIONS IN THE OIL AS A CONSEQUENCE OF EVAPORATION

THICKNESS OF OIL SLICK

	1 mm			5 mm			20 mm		
Time	$\leq C_{11}$	C_{12}-C_{16}	$\geq C17$	$\leq C_{11}$	C_{12}-C_{16}	$\geq C_{17}$	$\geq C_{11}$	C_{12}-C_{16}	$\geq C_{17}$
0	32.6	33.4	34.0	32.6	33.7	33.7	32.6	33.7	33.7
0.5	22.2	32.6	45.2	26.6	31.0	42.4	27.8	32.9	39.3
1	18.9	35.5	45.6	22.1	33.6	44.3	27.3	31.7	41.0
2	21.7	36.3	42.0	25.8	32.4	41.8	21.5	35.7	42.8
8	12.0	37.0	51.0	-	-	-	-	-	-
16	17.7	32.7	49.6	-	-	-	-	-	-
24	14.1	41.2	44.7	10.0	36.6	53.4	13.1	34.6	52.3
48	7.6	42.4	50.0	8.5	38.3	53.2	-	-	-
72	4.5	26.0	69.5	-	-	-	-	-	-
86	7.6	43.4	49.0	8.7	37.1	54.2	12.9	39.0	48.1
120	5.6	35.7	58.7	-	-	-	-	-	-
144	2.1	33.2	64.7	4.9	37.9	57.2	11.9	43.8	44.3

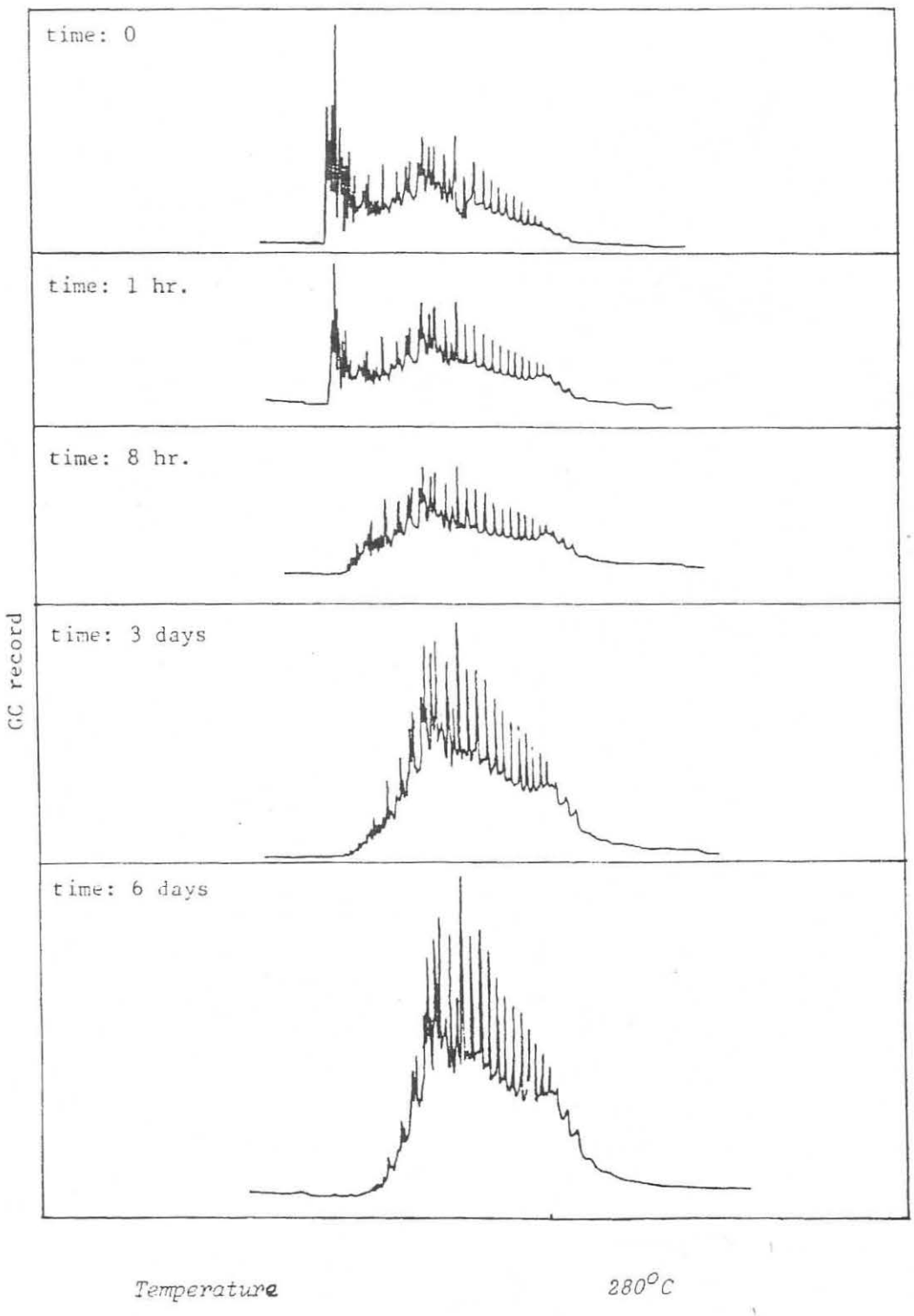

FIGURE 3 GC RECORD SHOWING THE EVAPORATION OF CRUDE OIL, FROM 1 mm OIL FILM.

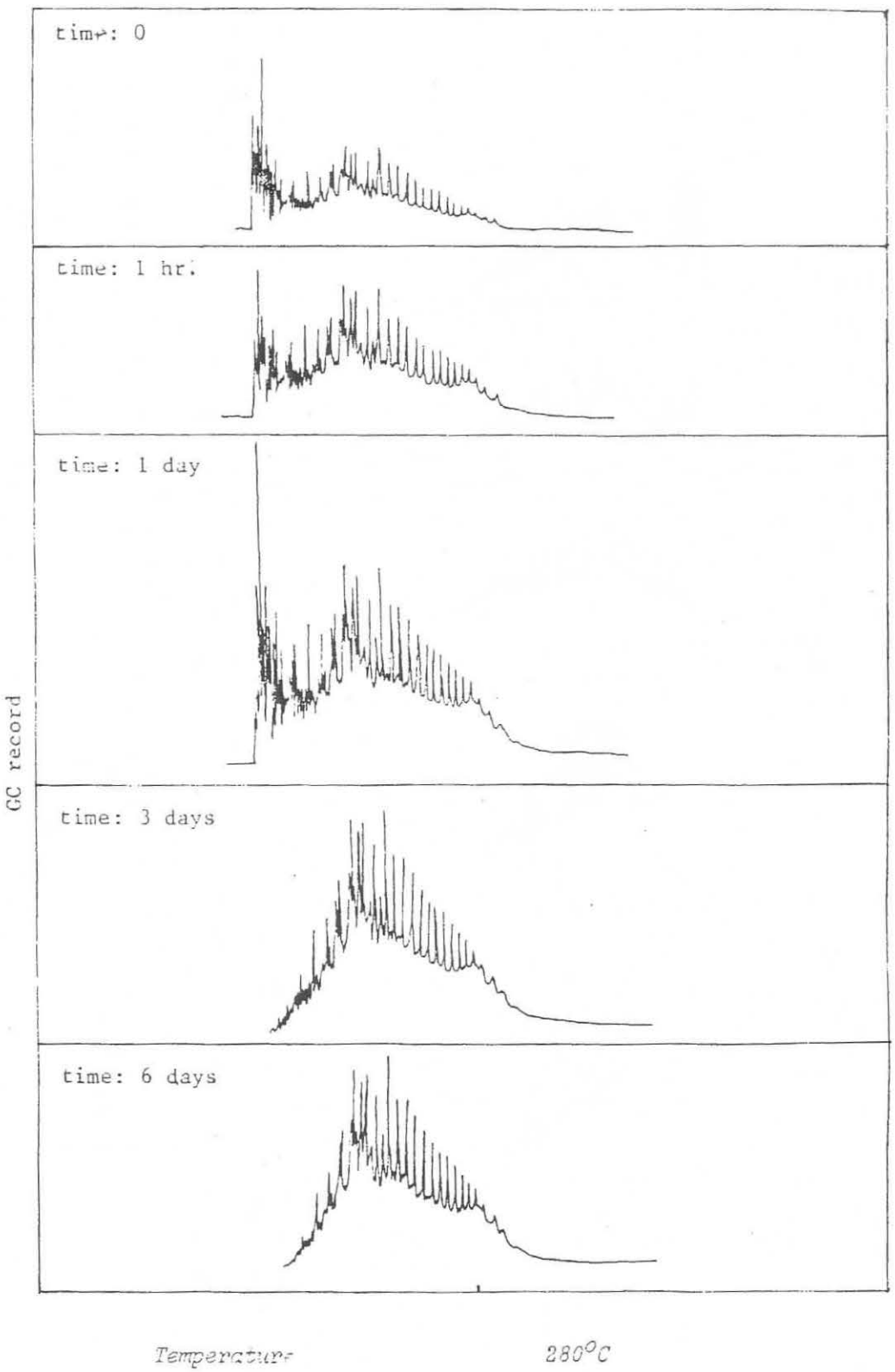

FIGURE 4 GC RECORD SHOWING THE EVAPORATION OF CRUDE OIL, FROM 5 mm OIL FILM.

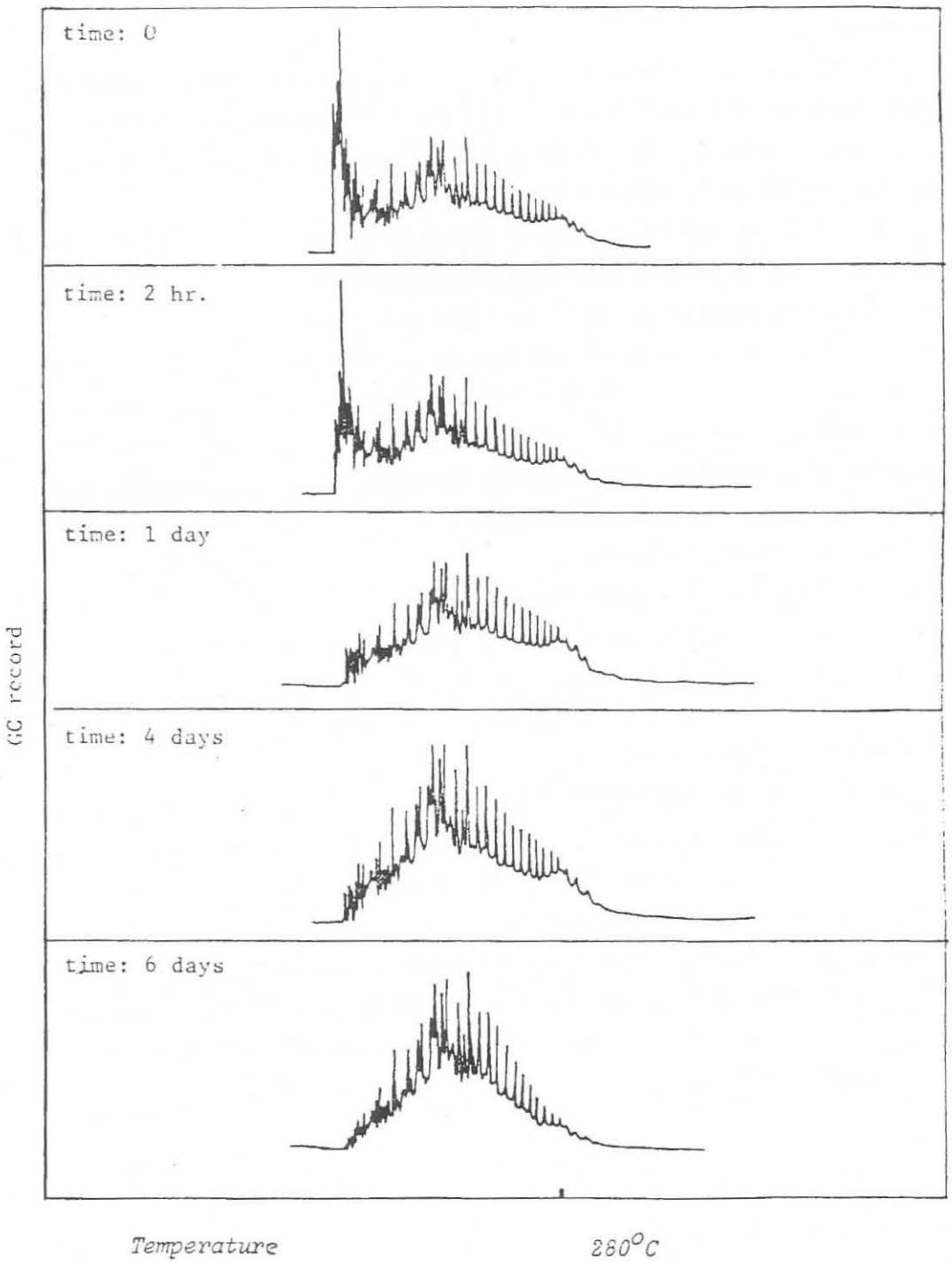

FIGURE 5 GC RECORD SHOWING THE EVAPORATION OF CRUDE OIL, FROM 20 mm OIL FILM.

film had evaporated, while only 41% and 15-25% respectively of the 5 mm and the 20 mm oil film had evaporated.

The total change in the fingerprint of the oil after one year is shown in Figure 6, and after four years in Figures 7 and 8. A small scale difference in the lighter fractions of the oil can be noticed. These fingerprints indicate a fairly low rate of total weathering of oil after the initial evaporation had terminated.

To conclude the decomposition study it should be noted that as 10 L of crude were added per m^2, after four years only 2.34% of oil could be detected in the top 3 cm of the soil profile. Visual inspections of the soil cores indicate that the oil had not penetrated to deeper layers. In the fertilized test site only 1.75% oil could be found. This means that while 10 L/m^2 were added, only about 430 g/m^2 oil could be found in the "oil alone" plot. Correspondingly only 320 g/m^2 could be found in the fertilized plot. This means that most of the oil is transported out from the slick area, possibly by snow melting and ice action. On the other hand, it can be seen that the difference between the fertilized and the "oil alone" slick represents about 110 g oil per m^2. The decomposition of this amount of oil must be regarded as the result of increased microbiological activity. This amount of oil can be compared to the estimated increased decomposition caused by fertilizing shown in Figure 1. Here an increased carbon release of approximately 98 g carbon is estimated. If it is estimated that the source of this carbon release from the soil is oil it represents approximately 112 g oil.

These results show that oil does decompose microbiologically at a rate of at least 55 - 96 g/m^2/year. Although this figure is small compared to the total removal of oil from this beach, the results show that oil can be acted on by microbial tools. An important point in this context may be that microbial oil decomposition mainly took place in the sticky surface of the oil slick. In this way, the increased microbial degradation of oil did decrease the chance for oil contamination of higher animal life. Consequently the oil slick had, in a way, been rendered less noxious in situ. A visible demonstration of this effect may be seen in Figure 9.

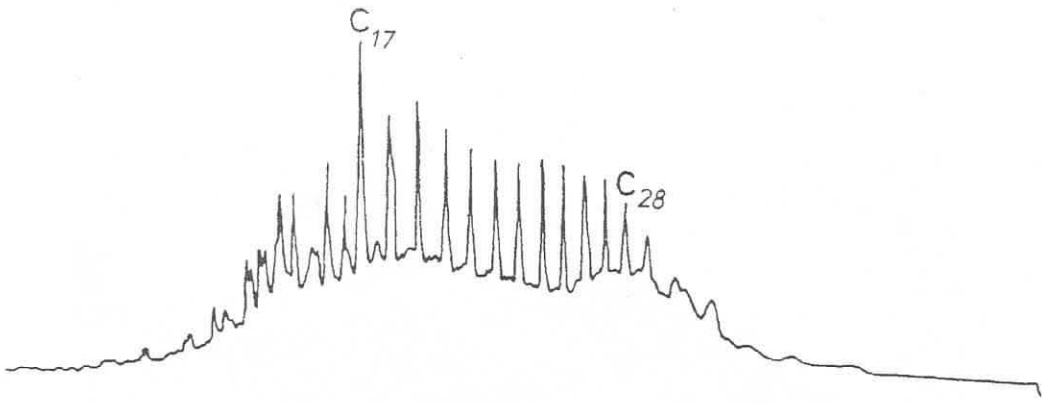

FIGURE 6 GC RECORD OF OIL AFTER ONE YEAR OF DECOMPOSITION

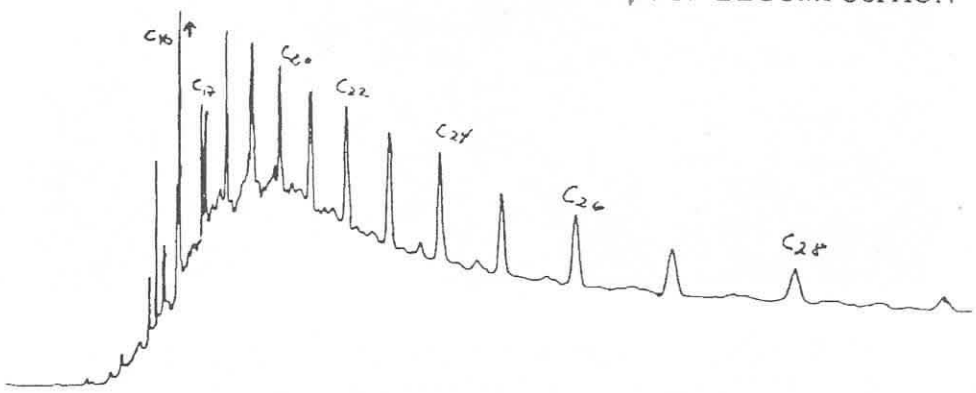

FIGURE 7 GC RECORD OF OIL EXTRACTED FROM THE "OIL ALONE" TEST SITE

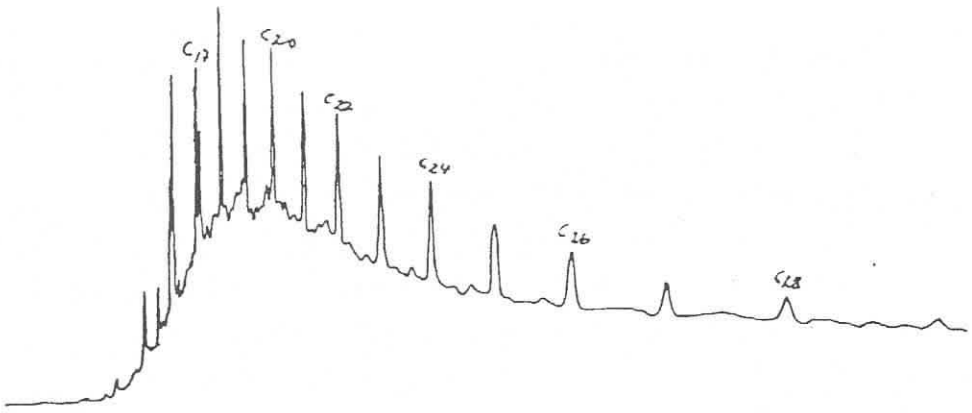

FIGURE 8 GC RECORD OF OIL EXTRACTED FROM THE "OIL AND FERTILIZER" TEST SITE

FIGURE 9 VISUAL DEMONSTRATION OF THE FERTILIZING EXPERIMENT
The fertilized areas are the two dark squares in the centre of the picture. (Picture taken one year after addition of fertilizer).

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